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Lithostratigraphic revision of the Upper Cambrian Cairnside Formation, upper Potsdam Group, southwestern Quebec[1]

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Abstract : The contact between the Covey Hill and overlying Cairnside formations (Potsdam Group) is exposed in the Ducharme quarry near the village of Covey Hill. It is the first time that the contact is identified from a surface section. The upper part of Covey Hill observed below this contact is characterized by a thick- to medium-bedded, light- and medium-grey, coarse-grained, pebbly subarkose lithofacies. The Cairnside Formation consists of a lower unit of thickly bedded to medium-bedded, coarse-grained, burrowed, white quartz arenite and an upper unit characterized by beds similar to those of the lower unit with thinly bedded to lenticular, medium-grey, coarse-grained dolomitic sandstone. The upper contact of the Cairnside Formation is recognized from a core, and is placed at the top of the highest clean quartz arenite above which such lithofacies does not exist or is extremely subordinate relative to the dolomitic sandstone and sandy dolostone interbeds of the overlying Theresa Formation.

Résumé : Le contact entre les formations de Covey Hill et de Cairnside (Groupe de Potsdam) est présent dans la carrière Ducharme, à proximité du village de Covey Hill. La description que nous présentons de ce contact est la première qui soit faite à partir d'une coupe affleurante. La partie supérieure de la Formation de Covey Hill est caractérisée par un lithofaciès de subarkose grossière à caillouteuse de couleur grise, disposée en lits de grande à moyenne épaisseur. La Formation de Cairnside consiste en une unité inférieure de quartzarénite grossière de couleur blanche, bioremaniée, à lits de grande à moyenne épaisseur et en une unité supérieure similaire à la précédente, mais qui renferme des lits minces à lenticulaires de grès dolomitique grossier de couleur grise. Dans les coupes en forage, le contact supérieur de la Formation de Cairnside est placé au sommet du lit de quartzarénite le plus haut, au-delà duquel ce lithofaciès n'existe plus ou est excessivement rare par rapport au grès dolomitique à interstrates de dolomie gréseuse de la Formation de Theresa sus-jacente.

[1] Contribution to the Appalachian Foreland and St. Lawrence Platform Architectures in Quebec, New Brunswick and Newfoundland NATMAP Project

INTRODUCTION

The studied area is part of the St. Lawrence Lowlands of southwestern Quebec, and is centered by the City of Montréal (Fig. 1). In this region a (?)[Late Proterozoic]–Lower Paleozoic sedimentary succession disconformably overlies Grenvillian crystalline rocks of Precambrian age. The lower part of the succession ((?)[Late Proterozoic]–Lower Ordovician) comprises siliciclastic-dominated units of the Potsdam Group (Covey Hill and Cairnside formations) overlain by Lower to lower Middle Ordovician, carbonate-dominated Beekmantown Group (Clark, 1966, 1972a, b; Hofmann, 1972; Globensky, 1987; Bernstein, 1991, 1992; *see also* Fig. 2). Despite the fact that the sedimentary units of southwestern Quebec have been of interest to researchers since the time of Logan (1863) and Ells (1895) (*see* Bernstein (1991, 1992) for more details), stratigraphic and sedimentological attributes of the Potsdam Group are poorly known. This is mostly due to the limited presence of 'reasonably thick' outcrops and limited exploration wells. As part of the new eastern Canada NATMAP project led by the Quebec Geoscience Center, we are currently revising the (?)[Late Proterozoic]–Lower Paleozoic succession of southwestern Quebec in the hope of unravelling the evolution of the Laurentian margin in this region. As a preliminary contribution, we document here some aspects of the lithostratigraphic and sedimentological attributes of the Upper Cambrian Cairnside Formation. We recognize, for the first time, the Covey Hill–Cairnside boundary in a surface (quarry) section. We also subdivide the Cairnside Formation into two informal lithological units. The upper contact of the formation is recognized from a subsurface core, and it is in agreement with previous work (e.g. Clark, 1972a; Bernstein, 1991, 1992).

PREVIOUS WORK AND TERMINOLOGY

The term "Potsdam Sandstone" was originally proposed by Emmons (1838) for the lowest siliciclastic sedimentary section, overlain by the "Transition beds" and carbonate-dominated "Calciferous" beds, along the northwestern edge

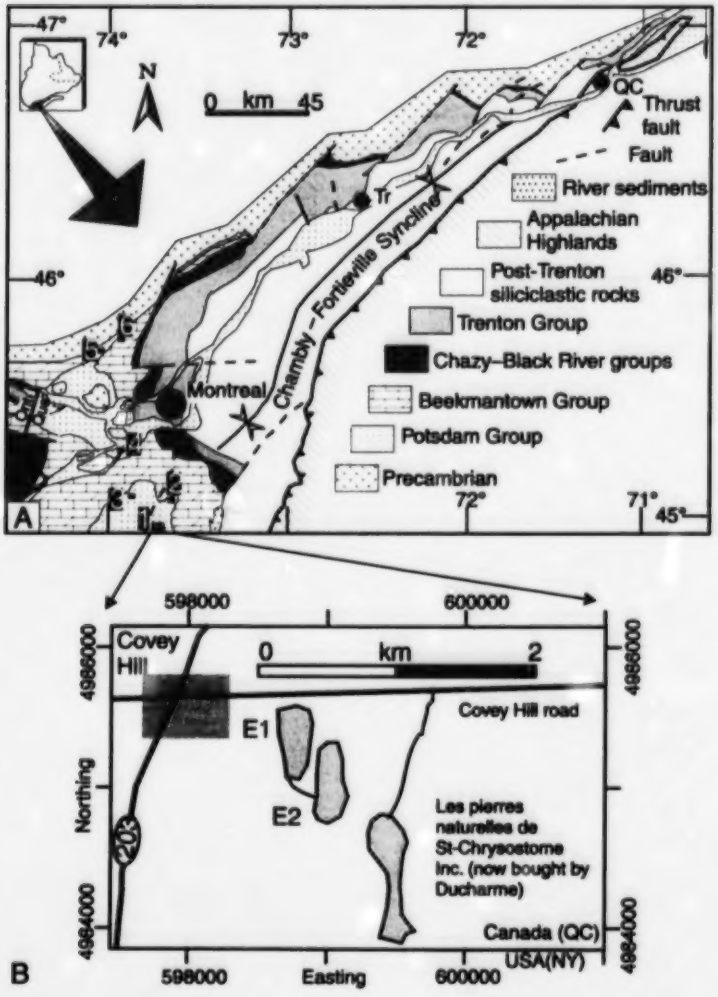

Figure 1.

A) Geological map of southwestern Quebec with localities mentioned in the text. B) Detailed location map of the Ducharme quarry (E1 and E2 excavations) where the highest beds of the Covey Hill Formation (Rivière Aux Outardes Member, unit A) and the Covey Hill–Cairnside contact are exposed.

of the Adirondac Massif of New York State. Logan (1863), and later Raymond (1913), imported the Potsdam Sandstone to Quebec and Ontario, and applied the term to the lowest silicilastic section of the St. Lawrence Lowlands. Clark (1966) also adopted the term but raised it to a group status (i.e. Potsdam Group) with internal subdivisions of formations and members. Most of the later researchers in both southwestern Quebec and eastern Ontario used the Potsdam Group for the lowest siliciclastic section in both regions, although controversies in its internal subdivisions existed in the past (Clark, 1966, 1972a; Lewis, 1971; Globensky, 1982, 1986, 1987; Wolf and Dalrymple, 1984; Williams and Telford, 1986; Dix et al., 1997). The Potsdam Group as defined by Clark (1966, 1972a) consisted of the Covey Hill and Châteauguay formations with further subdivisions into members (Fig. 2). The nomenclature of Clark (1966, 1972a) was used by Hofmann (1972) and Lewis (1971) except that they attributed Clark's Norton Creek Member (upper Châteauguay Formation) to the Theresa Member — a term originally proposed by Cushing (1908) for the Transition beds of northwestern upstate New York. Conversely, Clark (1972b) used the term Theresa Member instead of Norton Creek Member. Globensky (1981) also followed Clark's (1966, 1972a) subdivisions, but he later

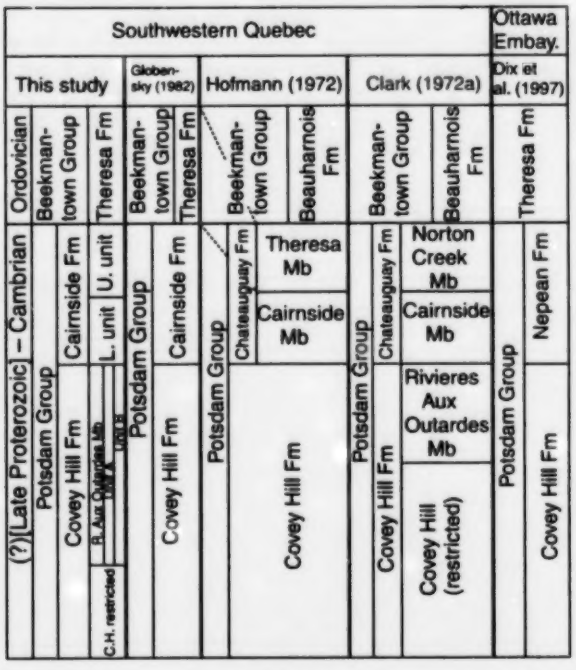

Figure 2. *Correlation chart showing stratigraphic nomenclature applied to the lower Lower Paleozoic strata in southwestern Quebec and the Ottawa Embayment (Embay.). Recognition of a carbonate-rich unit in the uppermost Covey Hill beds in the region of St.-Canut, north of Montréal, allowed us to informally subdivide the upper Rivière Aux Outardes of the Covey Hill Formation into two units (unit A = the carbonate free portion, and unit B = the carbonate-rich unit. C.H. = Covey Hill.* See *Salad Hersi and Lavoie (2000) for further discussion of unit B).*

(Globensky, 1982) raised the Cairnside and Theresa members to formation ranks (i.e. Cairnside and Theresa formations, respectively). Based on fossil evidence, Globensky (1982) inferred an Ordovician age for the Theresa Formation and put it into the overlying Ordovician Beekmantown Group, whereas the Cairnside Formation remained in the upper part of the Potsdam Group (Fig. 2). The inclusion of the Theresa Formation into the Beekmantown Group was proposed earlier by Raymond (1913) and more recently by Bernstein (1991, 1992).

UPPERMOST BEDS OF THE COVEY HILL FORMATION

The highest beds of the Covey Hill Formation are well exposed in the northwestern quarry of Ducharme (locality 1, Fig.1; *see also* Globensky's (1986) locality 78) near the hamlet of Covey Hill. The quarry consists of two excavations (E1, E2, Fig. 1) separated by an unexploited zone, and the Covey Hill–Cairnside contact lies in the upper part of excavation 2. Beds exposed in the northern excavation (E1) and the lower part of excavation 2 belong to the Covey Hill Formation (Fig. 3). They consist of medium-bedded to thickly bedded, coarse- to very coarse-grained (0.28–1.5 mm), light- to medium-grey subarkose. Pebbles are present in most of the beds, and are scattered either throughout, in the basal part or in the upper part of the beds. Medium-grey mudrock lenses and thin beds to laminae are locally present. Feldspathic grains reach as high as 15%, but are usually less than 10%. Tabular and trough crossbedding, and planar (horizontal) bedding are common. The medium-grey subarkose beds are characterized by internal lensoid structures due to well developed trough (festoon) crossbedding cosets (Fig. 4A). A 15 cm thick bed of horizontally burrowed, medium-grey mudrock (siltstone) lies 1.16 m below the upper contact of the formation (Fig. 3). The highest beds of the Covey Hill Formation (the 1.16 m thick strata above the burrowed mudrock) consist of light-grey, poorly sorted, fine- to coarse-grained (0.187–0.844 mm) subarkose. These upper beds also contain phosphatic fragments of inarticulate brachiopod (?*Lingulepis* sp.). Thick beds of white, burrowed quartz arenite of the Cairnside Formation lie above this fossiliferous, subarkosic sandstone of the Covey Hill Fomation (Fig. 4B, C).

The upper beds of the Covey Hill Formation argue for a deposition in a shallow-marine environment as manifested by inarticulate brachiopod fragments and an underlying burrowed mudrock bed (Fig. 3). Such a depositional environment was inconclusively inferred by Clark (1966) based on possible swale crossbedding in the Rivière Aux Outardes Member, upper Covey Hill Formation. Later workers (e.g. Hofmann, 1972; Globensky, 1986) supported a fluvial depositional setting for the formation.

Other data from a quarry near St.-Canut, north of Montréal (Fig.1, locality 5) show that beds underlying typical Cairnside sandstone units are lithologically different from the upper beds of the Covey Hill Formation described above. These rocks predate Cairnside strata in the St.-Canut area, are carbonate rich, and contain various types of fossils. Based on

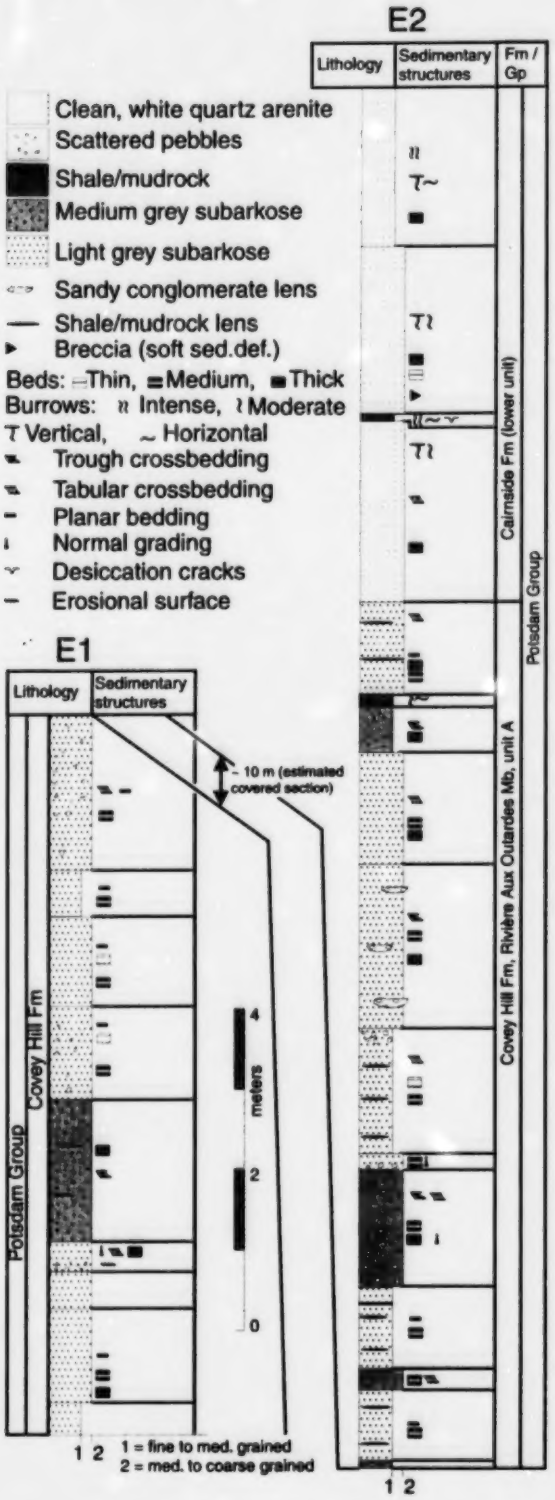

Figure 3. Stratigraphic log from the two excavations (E1 and E2) of the Ducharme quarry. The two excavations are separated by an estimated interval of 10 m. Excavation 2 section shows the Covey Hill–Cairnside contact. The Covey Hill Formation (Rivière Aux Outardes Member, unit A) consists of medium- to coarse-grained, medium and light grey subarkose interbeds, whereas beds of the Cairnside Formation consist of well burrowed, clean quartz arenite lithofacies.

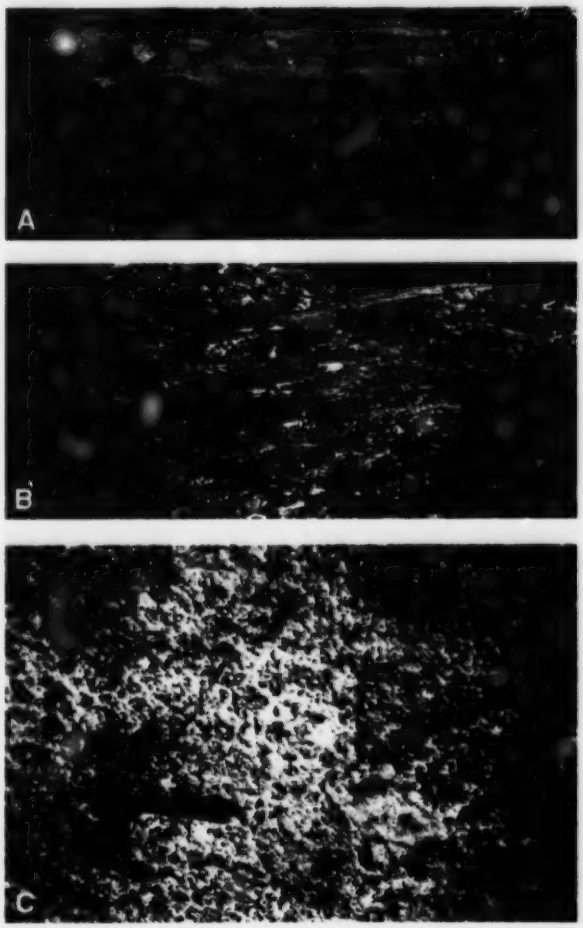

***Figure 4. A)** Medium-grey subarkose bed characterized by internal lensoid structure due to well developed trough crossbedding. Hammer is 32 cm long. **B)** Section showing the Covey Hill–Cairnside contact; 'CS' stands for contact surface. The contact is sharp and apparently conformable. Vertical Cairnside section in the upper left part of the photograph is 2.27 m thick. **C)** Burrow-mottled surface of the clean quartz arenite lithofacies of the Cairnside Formation. Photograph is from the top view of the highest bed of the Ducharme quarry, excavation 2. Hammer is 32 cm long.*

these regional differences in the upper part of the Covey Hill Formation (equivalent to Clark's (1966) Rivière Aux Outardes Member), we informally subdivide the Rivière Aux Outardes Member into two, (?)laterally equivalent units (Fig. 2). We assign the carbonate-free beds occurring in the Covey Hill area, south of Montréal (e.g. Ducharme quarry) to unit A, and the carbonate-rich beds occurring in the St.-Canut area, north of Montréal to unit B (locality 5). A separate paper dealing with unit B and the possibility of existence of a carbonate platform predating Cairnside strata in southwestern Quebec is presented by Salad Hersi and Lavoie (2000).

CAIRNSIDE FORMATION

The Cairnside Formation, as described here, is correlative with the Cairnside Member of Clark (1966, 1972a) and Cairnside Formation of Globensky (1982). None of the available surface sections offers a complete succession of the Cairnside Formation, but subsurface data from previous work shows that the formation is about 44 m (145 feet) thick (Clark, 1972a, p. 25). The thickest section measured during our work is from a core at locality 6 (Fig. 1) and includes a 32.2 m thick (105.5 feet) section of Cairnside sandstone in its lower part. This core also shows the upper contact of the Cairnside Formation with the Theresa Formation (lowest unit of the Beekmantown Group). The contact is placed at the top of the highest clean quartz arenite above which this lithofacies (i.e. clean quartz arenite) does not exist or is extremely subordinate relative to the medium- to dark-grey, dolomitic sandstone and sandy to pure dolostone interbeds of the overlying Theresa Formation.

Clark (1966) divided its Cairnside Member into two informal units; these are also recognized in our work. Lithological description of the two units and the nature of the contact between them are discussed below.

Lower unit

The lower unit of the formation is exposed in localities 1, 2, and 5 (Fig. 1). Localities 1 and 5 show the lowest beds of the unit, as well as the Covey Hill–Cairnside contact (Fig. 3, 4B), whereas locality 2 (Schink quarry, Globensky's (1986) type-section for the Cairnside Formation) shows the upper part of the unit and its contact with the upper unit of the Cairnside Formation (Fig. 5, 6A).

The lower unit of the formation consists of thickly bedded to medium-bedded, coarse-grained, clean, creamy white quartz arenite. It weathers to light pale, yellowish grey to white. Under the microscope, the rock is characterized by either coarse-grained uniform mosaic of quartz grains or normally grading laminae and thin beds of coarse-grained (1.053–0.576 mm) and medium-grained (0.393–0.227 mm) mosaics of quartz grains. The latter are tightly packed, with linear, serrated, and/or concave-convex contacts, and well to moderately rounded. Grains are commonly cemented by silica due to quartz overgrowth. Rare K-feldspar fragments (mainly microcline) are present in the finer grained population. Thin beds to laminae and lenses of medium-grey mudrock are locally present.

Sedimentary structures and biological elements in the unit include tabular crossbedding, planar bedding, unidirectional (current) ripples, vertical (*Skolithos* sp.) burrows (Fig. 4C), *?Climatichnites* sp. trace fossils, desiccation cracks, scour surfaces, and normal gradation. Trough crossbedding is also present but not common. Some beds show pervasive biogenic reworking of the sediment, producing a densely packed burrow network similar to the *Ophiomorpha* ichnofabric of Bottjer and Droser (1994). In the lower part of the unit at locality 1, there is a brecciated zone due to soft-sediment deformation. The breccia clasts are lithologically similar to the clean quartz arenite of the Cairnside sandstone.

Upper unit

The upper unit of the Cairnside Formation is separated from the lower unit by an erosional surface (Fig. 5, 6A). The upper unit consists of two interbedded lithofacies, 1) quartz arenite lithofacies (Lf-1), which is similar in every sense (grain size, sedimentary structures, colour, etc.) to that of the lower unit and overwhelmingly dominates the succession, and 2) dolomitic sandstone lithofacies (Lf-2), which occurs as thin to medium beds and lenses interbedded with lithofacies Lf-1 (Fig. 6A–C). Lithofacies Lf-2 also exists as granule- to cobble-size rip-up clasts incorporated with lithofacies Lf-1 (Fig. 6A). Sedimentary structures in lithofacies Lf-2 include tabular and herringbone cross-stratification in some places, and laminae and thin beds that are conformable with the forsets of the crossbedded sandstone of lithofacies Lf-1 (Fig. 6A). Load structures, including flame (dolomitic sandstone injected into the overlying quartz arenite bed) and ball-and-pillow (discrete, rounded lenses of lithofacies Lf-2 separated by Lf-1) structures, are also locally well developed (Fig. 6B).

Petrographically, the dolomitic sandstone lithofacies (Lf-2) is characterized by framework-supported, moderately sorted, very coarse- to medium-grained (1.130–0.250 mm) quartz grains with a fine crystalline dolomite 'matrix' (Fig. 6D). The fine dolomite crystals appear to have had recrystallized from a blocky-type dolomite cement. The latter is inferred from background cement which shows a single extinction pattern. This suggests that the fine dolomite crystals originated from recrystallization of another older cement, but not as a real matrix syndepositional with the framework grains. However, in the upper part of the unit (e.g. locality 4), there is a real dolomicrite matrix in lithofacies Lf-2. In fact, in some localized zones within a generally framework-supported dolomitic sandstone bed, the rock may be matrix supported. This observation was also reported by Clark (1966, p. 22).

Lithofacies 2 is not laterally continuous, and may disappear in some sections in Quebec. For instance, the lower 32.2 m of a core from locality 6 (Fig. 1, well # 1) shows clean quartz arenite (lithofacies Lf-1) of the Cairnside Formation, and no single bed, lamina, or clast of lithofacies Lf-2 has been seen. Although absence of lithofacies Lf-2 from the core

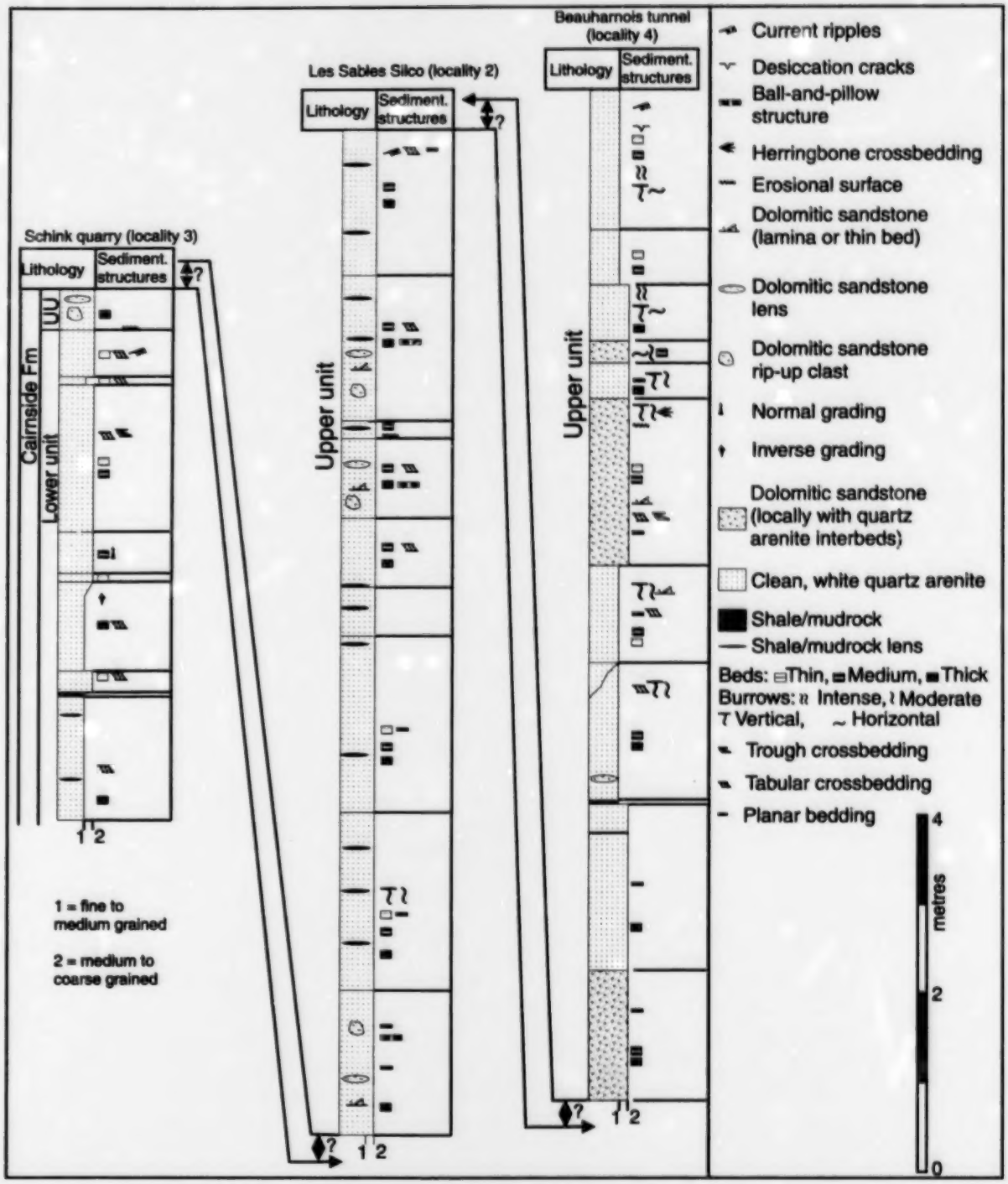

Figure 5. *Lithostratigraphic correlation of three sections showing the Cairnside Formation. Note that the contact between the lower and upper units of the formation is exposed in the upper part of the Schink quarry (locality 3), and the other two sections (localities 2, 4) belong to the upper unit. Because of lack of marker bed(s) across the mapped sections, it is not possible to satisfactorily tie among them. However, their relative stratigraphic positions are inferred from the lower unit-upper unit contact (locality 3 relative to locality 2) and an upward increase of the dolomitic sandstone lithofacies (locality 2 relative to locality 4).*

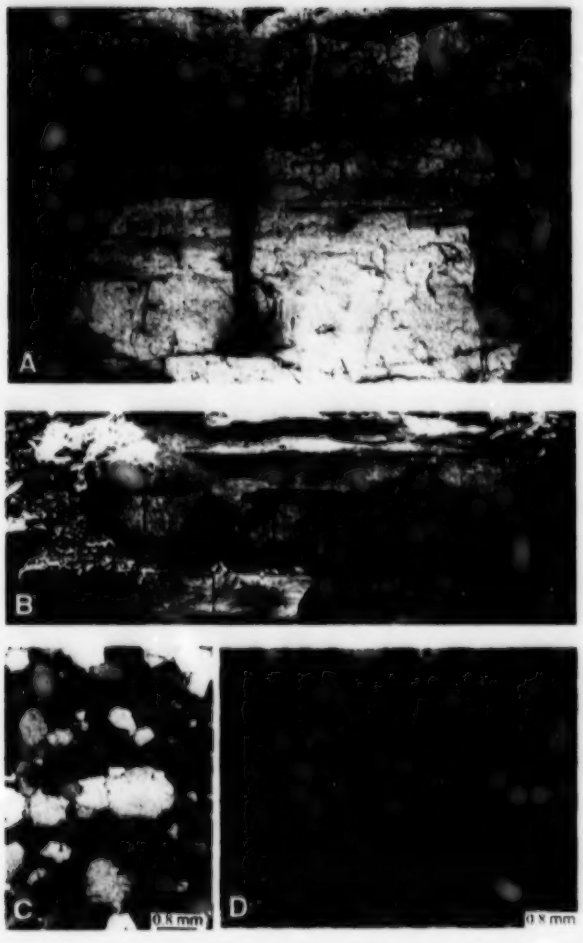

***Figure 6. A)** Erosional surface marks the contact between the lower and the upper units of the Cairnside Formation (surface along down-facing arrows). In the bed above the contact, medium-grey, dolomitic sandstone lithofacies (Lf-2) is manifested as pebble- to cobble-size rip-up clasts and thin laminae (vertical arrows) conformable with the white sandstone lithofacies (Lf-1). Schink quarry, locality 3, hammer is 32 cm long. **B)** Lenses (up-facing arrows) and thin beds of the medium-grey dolomitic sandstone lithofacies (Lf-1) occurring within the cleaner facies (Lf-1) of the upper Cairnside Formation. The lenses shown here are ball-and-pillow structures. Note also the flame structure in the lower bed (down-facing arrows), and that the bed laterally (to the left side of the photograph) subdivides into thinner laminae and then disappear; Les Sables Silco quarry, locality 2. Pencil is 14 cm long. **C), D)** Thin section micrographs from the quartz arenite lithofacies (Lf-1) and the dolomitic sandstone lithofacies (Lf-2), respectively, of the upper unit of the Cairnside Formation.*

could be related to limited areal representation of the well, it could also be due to lateral wedging-out of the lithofacies. Where lithofacies Lf-2 is absent from the section, the two units of the Cairnside Formation can not be distinguished and, thus, the whole formation is represented by lithofacies Lf-1.

DEPOSITIONAL ENVIRONMENT

Sedimentary structures preserved in the formation (e.g. trough, tabular, and herringbone crossbedding, desiccation cracks, *Skolithos* sp., and other pervasive burrows) suggest a high- to moderate-energy, tide-dominated, shallow subtidal to intertidal depositional setting. The lithofacies attributes of the formation are comparable to those of Runkel et al.'s (1998) shoreface (B) and Goldring and Bridges' (1973) shoreline associations.

The dolomitic sandstone lithofacies (Lf-2) of the upper unit probably originated as penecontemporaneous precipitation and dolomitization of micrite and cement in temporarily sheltered locations (e.g. interdune troughs) and stabilized foresets. This is inferred from its lenticular nature and conformity with the foresets of the quartz arenite lithofacies (Lf-1). High-energy currents during deposition of the clean quartz arenite reworked partially the dolomitic sandstone lenses and laminae and produced rip-up clasts within the quartz arenite lithofacies.

CONCLUSIONS

The contact beween the Covey Hill and Cairnside formations (Potsdam Group, southwestern Quebec) is exposed at the Ducharme quarry near Covey Hill village. The contact separates the lower arkosic sandstone (Covey Hill Formation) characterized by interbedded lithofacies of thickly bedded, light-grey arkose, and medium grey, intensely trough crossbedded arkose on one side, from the overlying thickly bedded, well burrowed, white, clean quartz arenite (Cairnside Formation) on the other side.

The Cairnside Formation consists of two informal units, 1) a lower thickly to medium bedded, clean, white quartz arenite; and 2) an upper unit consisting of interbedded quartz arenite (lithofacies Lf-1 dominant) similar to that of the lower unit, and subordinate, thinly bedded to lenticular, coarse-grained, crossbedded, medium-grey dolomitic sandstone (lithofacies Lf-2).

Lithofacies Lf-2 is not laterally continuous, and appears to be absent in sections north of Montréal (e.g. locality 6). In this case, the two units of the formation are indistinguishable, and the whole formation is represented by lithofacies Lf-1.

The Cairnside Formation was deposited in a moderate- to high-energy, tide-dominated, shallow-marine environment (subtidal to intertidal and shoreline sand bars). Micrite matrix possibly produced in sheltered interdune troughs and on foreset slopes and early carbonate cementation produced lenses and thin beds of lithofacies Lf-2 in the upper unit.

High-energy currents reworked semiconsolidated lenses and beds of lithofacies Lf-2, and produced granule- to cobble-size rip-up fragments within lithofacies Lf-1.

The upper contact of the Cairnside Formation is placed at the top of the highest white, dolomite-free quartz arenite bed above which the quartz arenite lithofacies (typical for the Cairnside Formation) does not occur or is extremely subordinate relative to the dolomitic sandstone and sandy to pure dolostone of the overlying Theresa Formation (lower Beekmantown Group).

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